

## **Nanotechnology: Prospects of Agricultural Advancement**

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### **ABSTRACT**

Nanotechnology has emerged as one of the most innovative scientific field in agriculture. It provides opportunity to develop improved systems for monitoring environmental conditions and delivering nutrients or pesticides as appropriate, improve our understanding of the biology of different crops and thus potentially enhance yields or nutritional values. In addition, it can offer routes to added value crops or environmental remediation. The science of nanotechnology have the ability to work at the atomic, molecular and even sub-molecular levels in order to create and use material structures, devices and systems with new properties and functions. It is extremely diverse and multidisciplinary field, ranging from novel extensions of conventional device physics, to completely new approaches based upon molecular self-assembly to developing new materials with dimensions on the nanoscale. This paper reviews the nanotechnology with an emphasis on agricultural advancement.

**Keywords:** Nanotechnology, agriculture applications, crop improvement, Nanoscale, value addition.

### **INTRODUCTION**

A global food shortage is coming. There is no possible way that the world can produce enough food for that many people under the current system. According to the United Nations, about 800 million people in the world are suffering from food shortage and the number of people below poverty line has increased dramatically. In the past decades, the emergence of first-generation technology in agriculture leading to green

revolution have resulted in the transition from traditional agriculture to industrial agriculture. In this period, quantity and quality of agricultural products improved significantly, although this success was accompanied with excessive use of resources in the agricultural sector<sup>1</sup>.

Nanotechnology has the potential to revolutionize agriculture and food systems. Agricultural and food systems security, disease treatment delivery system, new tools for molecular and cellular biology, new

material for pathogen detection, protection of environment, and education of the public and future workforce are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems<sup>2</sup>. Nanotechnology was first introduced in 1959, in a talk by the Nobel Prize-winning physicist, entitled “There’s Plenty of Room at the Bottom” Richard Feynman proposed using a set of conventional-sized robot arms to construct a replica of themselves, but one-tenth the original size, then using that new set of arms to manufacture an even smaller set, and so on, until the molecular scale is reached. If we had many millions or billions of such molecular-scale arms, we could program them to work together to create macro-scale products built from individual molecules – a “bottom- up manufacturing” technique, as opposed to the usual technique of cutting away material until you have a completed component or product – “top-down manufacturing”. In 1986, K. Eric Drexler introduced the term nanotechnology. Scientific research really expanded over the last decade. Inventors and corporations aren’t far behind – today, more than 13,000 patents registered with U.S. Patent Office have the word “nano” in them. In its original sense, ‘nanotechnology’ refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products.

### **Fundamental and operational concepts**

One nanometer (nm) means one billion<sup>th</sup>, or  $10^{-9}$  parts of a meter. Like, the width of an average hair is 100,000 nanometers, human blood cells are 2,000 to

5,000 nm long, a strand of DNA has a diameter of 2.5 nm, and a line of ten hydrogen atoms is 1 nm. The ability to understand and manipulate matter at this level is closely related to the ability to understand and manipulate both matter and life at their most basic levels<sup>3</sup>. Two main approaches are used in nanotechnology. One is bottom-up approach in which materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition and second one top-down approach, nano-objects are constructed from larger entities without atomic level control.

Nature has evolved many bioorganic molecules that form complex structures with very complex dynamic behavior, called living cells. These cells, self assemble and form further complex structures culminating in intelligent life forms like humans and other animals. Even when damage is done to the living cells, nature has an amazing ability to heal itself by self –organization. E.g. when a living cell is wounded, the body reacts by sending white blood cells to ward off the infections killing the germs, red blood cells and proteins form a seal cover over the wound and also nutrients to the cells, so that they can produce new cells to replace the damaged cells. Such biomaterials are custom made for specific applications inspiring us to design materials that are ideal for a specific application rather than to cut and trim natural materials to suit our needs. When materials are built by the bottom-up process, one molecule at a time, it is possible to incorporate specific features at will. The concept of self-assembly with nanotechnology has the potential to impact diverse fields ranging from biology to materials science<sup>4</sup>.

## NANOMATERIALS

Nanotechnology will enable making high-quality products at a very low cost and at a very fast pace. Currently the main thrust of research in nanotechnology focuses on applications like electronics, automation, medicine and life sciences<sup>5</sup>. The materials with morphological similar to nanoscale, and especially those which have special properties stemming from their nanoscale dimensions. It includes carbon (tubes, particles), composites, metals & alloys (catalysts, silver), biomolecules (proteins, peptide, lipids, DNA templated circuits), polymers, glasses/amorphous materials (SiO, TiO, lead), ceramics etc. Other nano particle includes copper (wire, ribbon, etc.), gold, Sol-gel derived materials (metal alkoxides and metal chlorides) have diverse applications in optics, electronics, energy, space, (bio) sensors, medicine (e.g. controlled drug release) and separation (e.g. chromatography) technology.

Carbon nanotubes (CNTs) and fullerenes, the most important amongst nanomaterials, are allotropes of carbon with a cylindrical nanostructure<sup>6</sup>. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors. Their final usage, however, may be limited by their potential toxicity and controlling their property changes in response to chemical treatment. Nanoparticles or nanocrystals made of

metals, semiconductors, or oxides are of particular interest for their mechanical, electrical, magnetic, optical, chemical and other properties.

## Prospects of agriculture advancement

Food security has always been the biggest concern of the mankind. Nations, communities and Governments have been struggling with the issue since long. The experts of food industry estimate that nanotechnology will be incorporated into \$20 billion worth of consumer products by 2010<sup>7</sup>. Recent decades have seen even bigger challenges on this front. The future looks even bleaker with food shortage issue looming large. The challenge is how to feed the growing population by producing more on a stagnant or shrinking landscape; with lesser input costs and with lesser hazards to the eco-system. Another adjunct to this problem is how to add to the income of agricultural producers so as to sustain their motivation to grow crops. This also leads to the question as to how to add value to what is being produced and how to make the transaction in agro products smooth, safe and reliable. Thus, all across the world, an urgent need is being felt for more scientific and targeted management of the agriculture and food sector. Nanotechnology has answers to many of these challenges. In agriculture, some of the world's largest makers of pesticides, fertilizers, and other farm inputs and technologies are betting on nanotechnology to bring unprecedented precision to crop and livestock production.

<b>Major Challenges</b>	<b>What Nanotechnology offers</b>
<b>Food security for growing numbers</b>	Use of nanotechnology in agriculture and food industry can revolutionize the sector with new tools for disease detection, targeted treatment, enhancing the ability of plants to absorb nutrients, fight diseases and withstand environmental pressures and effective systems for processing, storage and packaging.
<b>Low productivity in cultivable areas</b>	Precision farming- Nanotechnology application here makes farming more targeted and scientific. Precision farming makes use of computers, global satellite positioning systems, and remote sensing devices to measure various parameters. Accurate information through applications of Nanotechnology for real time monitoring of soil conditions, environmental changes and diseases and plant health issues.
<b>Large uncultivable areas</b>	Bringing more areas under cultivation by Nanotechnology enabled environmental monitoring and management including cost effective water management through applications of nano science. Use of Nanotechnology in agriculture can thus change the land use pattern substantially.
<b>Shrinkage of cultivable lands</b>	The remedy is to enhance productivity through Nanotechnology driven precision farming and to maximize the output and minimize inputs through better monitoring and targeted action.
<b>Wastage of products</b>	Precision farming through use of Nanotechnology applications can also help to reduce agricultural waste and thus keep environmental pollution to a minimum.

<b>Perishability/ low shelf life</b>	Use of Nanotechnology in sensing applications will ensure food safety and security, as well as technology applications, which alert the customers and shopkeepers when a food is nearing the end of its shelf life. Nanotechnology based new antimicrobial coatings and dirt repellent plastic bags are a remarkable improvement in ensuring the safety and security of packaged food.
<b>Technology limitations</b>	Various devices designed through application of nanotechnology, which include biosensor for the detection of pesticides, herbicides, insecticide, viruses, microbe will bridge this gap to a great extent. Smart packaging developed by applying nano science concepts technology would be able to repair small holes/tears, respond to environmental conditions (e.g. temperature and moisture changes), and alert the customer if the food is contaminated
<b>Skill limitations</b>	Nanotechnology applications have the potential to produce easy-to-handle devices which reduce the dependence on human skills on many fronts, thus reducing the human risk
<b>Processing limitations</b>	Nanotechnology will change the existing system of food processing and will enhance the nutritional quality of food and will ensure the safety of food products. Addition of nano particles to existing foods to enable increased absorption of nutrients. Nanotechnology is already making an impact on the development of functional or interactive foods, which respond to the body's requirements and can deliver nutrients more efficiently. Research is on to develop new Nanotechnology driven "on demand" foods, which will remain dormant in the body and deliver nutrients to cells when needed. This is possible by applications of nano science.

<b>Packaging limitations</b>	Silver nano-particles can be embedded in polymeric materials such as PVC, PE, PET while polymerization occurs. Silver nanoparticles kill pathogens, bacteria, viruses and fungus and are used as a good and safe packaging pot. Such nanotechnology based packaging materials are 100 times more secure than the normal one for the storage of juices, milk and other agri-products. Food packaging films in the name of "hybrid system" films have enormous number of silicate nano particles. They massively reduce the entrance of oxygen and other gases, and the exit of moisture, thus preventing food from spoiling or drying.
<b>Diseases &amp; calamities</b>	The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes and diseases.
<b>Impact on Environment</b>	Nanotechnology will also help protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants. Nanotechnology Research also aims to make plants use water, pesticides and fertilizers more efficiently.

Applications of nanotechnology have the potential to change the entire agriculture sector and food industry chain from production to conservation, processing, packaging, transportation, and even waste treatment. Strategic applications of Nano Science can do wonders in the agriculture scenario. The nanotechnology works on crop sciences includes the production of Nanocapsules for delivery of pesticides, fertilizers, and other agrichemicals, Nanosensors for monitoring soil conditions

and crop growth, to deliver DNA to plants (targeted genetic engineering), delivery of growth hormones, delivery of vaccines, detection of animal and plant pathogens, nanochips for identity preservation and tracking. Nanotechnology also has to play a major role in crop improvement by explored through research in molecular and cellular biology to ensure food security. This can be achieved through better analysis of gene expression and regulation (nanobiotechnology), soil management,

plant disease diagnostics, efficient Pesticides & Fertilizers, Water Management, food processing, Post Harvest Technology, Monitoring the identity & quality of agricultural produces. Some of the progresses in agriculture sectors are as follows:

### **High Through put DNA sequence for crop improvement**

Research in nano-biotechnology is advancing toward the ability to sequence DNA in nano fabricated gel-free systems, which would allow for significantly more rapid DNA sequencing. Coupled with powerful approaches such as association genetic analysis, DNA sequencing data of the crop germplasm, including the cultivated crop gene pool and the wild relatives can potentially provide highly useful information about molecular markers associated with agronomically and economically important traits. Thus, nano biotechnology can enhance the pace of progress in molecular marker assisted breeding for crop improvement.

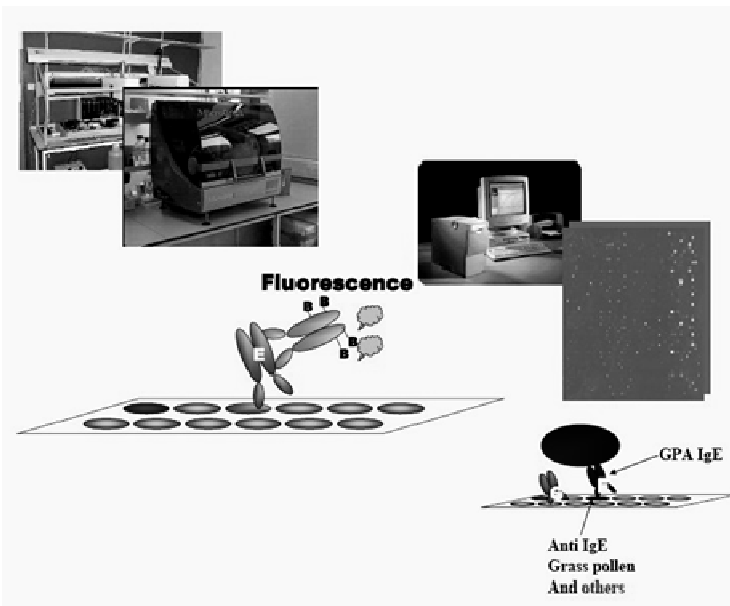
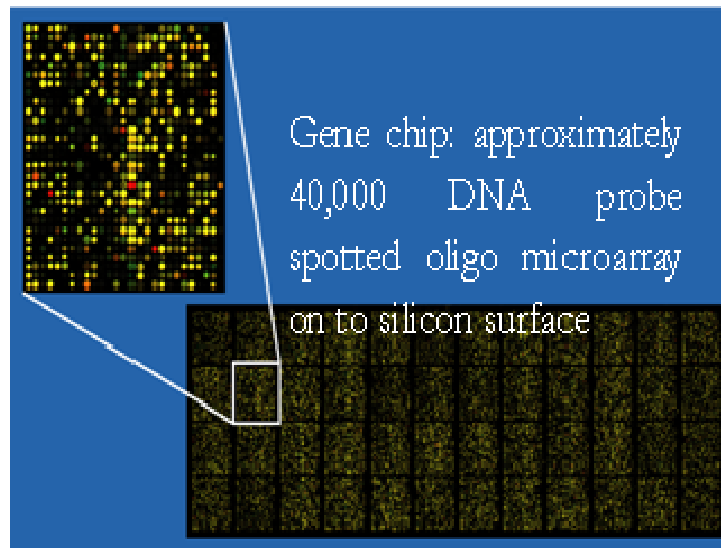
### **DNA Micro-arrays and Expression Profiling**

Microarrays based hybridization methods allow to simultaneously measure the expression level for thousands of genes. Such measurements contain information about many different aspects of gene regulation & function and indeed this type of experiments has become a central tool in biological research. The development of novel formats for sequence determination and patterns of genomic expression, which can have significantly higher throughput

than current technology is vital. Thousands of DNA or protein molecules are arrayed on glass/silica/beads slides to create DNA chips & protein chips respectively. Overall, nano fabrication techniques can be used for example to pattern surface chemistry for a variety of biosensor. & Biomedical application e.g. determination of new genomic sequences, scanning of genes for polymorphism that might have an impact on phenotype & comprehensive survey of the pattern of gene(s) expression in organisms when exposed to biotic/abiotic stress. DNA microarray are being used to detect mutations in disease related gene, monitor gene activity, identify gene important to crop productivity, improve screening for microbes used in bio remediation.

### **Protein Microarrays**

The structures and functions of proteins are much more complicated than that of DNA, and proteins are less stable than DNA. Each cell type contains thousands of different proteins some of which are unique. In addition, a cell's protein environmental conditions. Protein Microarrays are being used to discover protein biomarkers that indicate disease stages to assess potential efficacy & toxicity of pesticides to measure different protein production across cell types & developmental stages & in both healthy & diseased stages and to study the relationship between protein structure & function evaluate binding interactions between proteins & other molecules.



Proteinchip containing proteins to determine the characteristics of the antibodies/antigen from allergen, food etc.



### Atomically Modified Seeds

In March 2004, ETC group reported a nanotechnology research initiative in Thailand that aims to atomically modify the characteristics of local rice varieties. They drilled a hole through the membrane of rice cell to insert nitrogen atom that would stimulate the rearrangement of the rice. DNA, they are able to change the colour of local rice variety from purple to green. One of the attractions of this nano-scale technique is that it does not require the controversial technique of genetic modification.

### Nanosilica based transformation in Plant Cells

Francois Tournay, Brian Tsceoy, & colleagues at Iowa State University describe the use of silica nanoparticles to deliver foreign genetic material into plant cells in a process called transformation. Nanoparticles can be used to carry and release effectors, small molecules ( $\beta$ -estradiol) that induce the expression of genes within the plant cells in a controlled fashion.

### Nanofuels

Levesque's lab (University of Ottawa) is working on nanoconversion of agricultural materials into valuable products. The design and development of new nanocatalysts for the conversion of vegetable oils into biobased fuels and biodegradable solvents is already under scientific examination and could be greatly enhanced with the help of nanotechnological

abilities. This is based on the concept that the organic fuels at nano scale would be able to give greater energy with lesser energy loss during conversion.

### Particle Farming

Nanoparticles may not be produced in a laboratory, but grown in fields of genetically engineered crops what might be called "particle farming." Researches have shown that plants can also soak up nanoparticles that could be industrially harvested. Alfalfa plants grown on an artificially gold-rich soil. Gold nanoparticles in the roots and along the entire shoot of plants are then extracted simply by dissolving them in organic material. NCL, Pune, India have been carrying out similar work with geranium leaves immersed in gold-rich solution.

### Seeding Iron

Russian Academy of Sciences reported that germination of tomato seeds were improved by spraying a solution of iron nanoparticles on to the fields.

### Nanocides: Pesticides *via* Encapsulation

Pesticides containing nano-scale active ingredients are already on the market, and many of the world's leading agrochemical firms are conducting R&D on the development of new nano-scale formulations of pesticides. For example: BASF of Germany, the world's fourth ranking agrochemical corporation (and the world's largest chemical company), is conducting basic research on "Nanoparticles Comprising a Crop Protection Agent,"

whose ideal particle size is between 10 and 150nm & dissolves more easily in water: it is more stable and the killing-capacity of the chemical is optimized. Syngents's Primo MAXX Plant Growth Regulator (designed to keep golf course turf grass from growing too fast) and its Banner MAXX fungicide (for treating golf course turf grass) are oil-base pesticides mixed with water and then heated to create an emulsion. Syngenta claims that both products' were extremely small particle size of about 100 nm (or 0.1 micron) prevents spray tank filters from clogging, and the chemicals mix so completely in water that they won't settle out in the spray tank. They claim that the particle size of this formulation is about 250 times smaller than typical pesticide particles. According to Syngents, it is absorbed into the plant's system and cannot be washed off by rain or irrigation.

### **Soil Binder**

In 2003, ETC group reported on a nanotech based soil binder called SoilSet developed by Sequoia Pacific Research of Utah (USA). SoilSet is a quick setting mulch which relies on chemical reactions on the nanoscale to bind the soil together. It was sprayed over 1,400 acres of Encebadito mountain in New Mexico to prevent erosion followed forest fires, as well as on smaller areas of forest burns in Mendocino County, California.

### **Soil clean-up using Iron Nanoparticles**

A number of approaches are being developed to apply nanotechnology and particularly nanoparticles in cleaning up soil contaminated with heavy metals. A nano-

clean up method of injecting nano-scale iron into a contaminated site is developed. The particle flow along with the ground water and decontaminate in route, which is much less expensive than digging out the soil to treat it. This nano scale iron remain active in the soil for 6-8 weeks after which it dissolves in ground water and become indistinguishable from naturally occurring iron.

### **Quality Maintenance**

Identity Preservation (IP) is a system that creates increased customers with information about the particles and activities used to produce a particular crop or other agricultural products. Quality assurance of agricultural products safety and security could be significantly improved through IP at the nanoscale. Nanoscale IP holds the possibility of continuous tracking and recording of the history which a particular agricultural product experience. We envision nanoscale monitors linked to recording and tracking devices to improve identity preservation of food and agricultural products.

### **Smart Treatment Delivery Systems**

Today, application of agricultural fertilizers, pesticides, antibiotics, probiotics and nutrients is typically by spray or drench application to soil or plants, or through feed or injection systems to animals. Delivery of pesticides or medicines is either provided as "preventative" treatment or is provided once the disease organism has multiplied and symptoms are evident in the plant or animal. Nanoscale devices are envisioned that would have the capability to detect and treat an

infection, nutrient deficiency or other health problem, long before symptoms were evident at the macro-scale. This type of treatment could be targeted to the area affected. “Smart Delivery Systems” for agriculture can possess any combination of the following characteristics: time controlled spatially targeted, self regulated, remotely regulated, preprogrammed, or multi-functional characteristics to avoid biological barriers to successful targeting. Smart delivery system also can have the capacity to monitor the effects of the delivery of pharmaceuticals, nutraceuticals, nutrients, food supplements, bioactive compounds, probiotics, chemicals, insecticides, fungicides, vaccinations or water to people, animals, plants, insects, soils and the environment.

### **Nanofood**

A food is nanofood when nanoparticles, nanotechnology techniques or tools are used during cultivation, production, processing or packaging of the food. Nanofood is often associated with color & flavor improvement, better storage & preservation, pathogen detection, antimicrobial properties, intelligent packaging, etc. for example drinks that turn pink or yellow when microwaved, Nanocapsules incorporating tuna fish oil, a source of  $\Omega$ -3 fatty acids into bread. According to estimates: There are now over 600 nanofood products available on the market worldwide. The nanotechnology and nano-bio-info convergence will influence over 40% of the food industries up to 2025. The nanofood market has been soaring from \$2.6 billion in 2003 to \$5.3 billion in 2005 and is expected to reach \$20.4 billion in 2015. Nano – featured food packaging market will grow

from \$1.1 billion in 2005 to \$3.7 billion up to 2010. More than 600 Companies around the world are today active in research and development and production. USA is the leader followed by Japan and China. By 2015 Asia, with more than 50 percent of the world population will become the biggest market for the Nanofood with China in the leading position<sup>9</sup>.

### **Food processing**

Nanocapsulated flavor enhancers Nanocapsules to improve bioavailability of nutraceuticals in standard ingredients such as cooking oils Nanotubes and nanoparticles as gelation and viscosifying agents nanocapsule infusion of plant based steroids to replace a meat's cholesterol Nanoparticles to selectively bind and remove chemicals or pathogens from food Nanoemulsions and particles for better availability and dispersion of nutrients.

### **Food packaging**

Antibodies attached to fluorescent Nanoparticles to detect chemicals of foodborne pathogens. Nanosensors for temperature, moisture and time monitoring Nanoclays and nanofilms as barrier materials to prevent spoilage and oxygen absorption Electrochemical nanosensors to detect ethylene Antimicrobial and antifungal surface coatings with nanoparticles (silver, magnesium, zinc) Lighter, stronger, and more heat-resistant films with silicate nanoparticles modified permeation behavior of foils

### **Food supplements**

Nanosize powders were used to increase absorption of nutrients. Cellulose nanocrystals composite as drug carriers,

Nanochocleates (coiled nanoparticles) to deliver nutrients to cells without affecting color or taste of food, Vitamin sprays dispersing molecules into nanodroplets for better absorption.

### Health and environmental concerns

Some of the recently developed nanoparticle products may have unintended consequences. Researchers have discovered that silver nanoparticles used in socks only to reduce foot odor are being released in the wash with possible negative consequences. Silver nanoparticles, which are bacteriostatic, may then destroy beneficial bacteria which are important for breaking down organic matter in waste treatment plants or farms. A study at the University of Rochester found that when rats breathed in nanoparticles, the particles settled in the brain and lungs, which led to significant increases in biomarkers for inflammation and stress response. A major study published more recently in *Nature Nanotechnology* suggests some forms of carbon nanotubes – a poster child for the “nanotechnology revolution” – could be as harmful as asbestos if inhaled in sufficient quantities. Anthony Seaton of the Institute of Occupational Medicine in Edinburgh, Scotland, who contributed to the article on carbon nanotubes said "We know that some of them probably have the potential to cause mesothelioma. So those sorts of materials need to be handled very carefully." In the absence of specific nano-regulation it will be better to exclude engineered nanoparticles from organic food.<sup>1</sup> A newspaper article reports that workers in a paint factory developed serious lung disease and nanoparticles were found in their lungs.

### Regulation of Nanotechnology

Calls for tighter regulation of nanotechnology have occurred alongside a growing debate related to the human health and safety risks associated with nanotechnology. Furthermore, there is significant debate about who is responsible for the regulation of nanotechnology. While some non-nanotechnology specific regulatory agencies currently cover some products and processes (to varying degrees) – by “bolting on” nanotechnology to existing regulations – there are clear gaps in these regimes. Stakeholders concerned by the lack of a regulatory framework to assess and control risks associated with the release of nanoparticles and nanotubes have drawn parallels with bovine spongiform encephalopathy (‘mad cow’s disease), thalidomide, genetically modified food, nuclear energy, reproductive technologies, biotechnology, and asbestosis. There is insufficient funding for human health and safety research, and as a result there is currently limited understanding of the human health and safety risks associated with nanotechnology. As a result, some academics have called for stricter application of the precautionary principle, with delayed marketing approval, enhanced labelling and additional safety data development requirements in relation to certain forms of nanotechnology.

### CONCLUSIONS

Nanotechnology is the engineering of tiny machines i.e. the ability to build things from the ‘bottom up’ manufacturing because it aims to start with the smallest possible building materials, ATOMs using

them to create a desired product. By taking advantage of quantum level properties, MNT allows for unprecedented control of the material world, at the nanoscale, providing the means by which systems and materials can be built with exact specifications and characteristics.

Nanotechnology has wider uses in biotechnology genetics, plant breeding, disease control, fertilizer technology, precision agriculture, and allied fields, etc. However, currently there is a limited understanding of human health and safety risks associated with this technology. Controlled use of the technology will open opportunities for developing new materials and methods that will enhance our ability to develop faster, more reliable and more sensitive analytical systems. Overall the scenario presents us with the view that nanotechnology is here to stay.

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